UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
National Vehicle and Fuel Emissions Laboratory
2565 Plymouth Road, Ann Arbor, Michigan 48105

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MEMORANDUM

SUBJECT: Development of Light-Duty Emission Inventory Estimates in the Final Rulemaking for Tier 2 and Sulfur Standards

FROM: John W. Koupal
Office of Mobile Sources

TO: Docket A-97-10

The purpose of this memo is to detail our methods for deriving the emissions inventory estimates for NOx, VOC, SOx and PM_{10} from light-duty cars and trucks presented in the Tier 2 final rulemaking (primarily Chapter 3 of the Regulatory Impact Analysis, or RIA). For SOx and PM_{10}, the estimates presented in the RIA were derived from our analysis of air quality performed for the final rule. For NOx and VOC, two sets of estimates were presented in the RIA: estimates derived from our air quality analysis, and subsequent estimates which reflect updates to our Tier 2 Model based on new data and revised methodologies. Our derivation of the final rule air quality estimates and the updated Tier 2 Model estimates are discussed separately in this document.

This memo makes reference to a series of Microsoft Excel spreadsheet files used in the generation of the inventory numbers; many of the modeling inputs and results are contained in these files rather than presented in this document. All reports and computer files referenced in this document are contained in the Tier 2 Docket (A-97-10).

A. Derivation of Inventory Estimates Based on the Final Rule Air Quality Analysis

For our final rule air quality analysis, we contracted E.H. Pechan and Associates (Pechan) to generate emissions inventories for every county in the nation in calendar years 1996, 2007 and 2030. A complete description of this work is contained in the report by Pechan entitled “Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for the Tier 2 Final Rulemaking”, and is not elaborated on here. In short, however, we provided Pechan with adjustment factors which enabled them to convert county-specific output from MOBILE5 to our best estimate of how MOBILE6 would estimate emissions in each county.[1] These adjustment factors were based on the Notice of Proposed Rulemaking (NPRM) version of the Tier 2 Model. This spreadsheet emissions inventory model for light-duty cars and trucks incorporated several updates planned for MOBILE6 including revised exhaust emission rates, off-cycle and fuel sulfur effects, and the effects of increased truck sales.[2] As a result, the inventories generated for the air quality analysis reflect these updates according to the modeling inputs developed for the proposal.

Although the modeling inputs were identical for the proposal and our final rule air quality analysis, we consider the latter inventories to be more accurate. This is because the inventories generated for the air quality analysis were estimated at the county-by-county level, using county-specific inputs for parameters such as I/M program, age distribution, mileage accumulation and speed. The spreadsheet Tier 2 Model was originally designed to estimate national average emissions, and is less suited for providing estimates of emissions for a specific local area. This is evident by the fact that the air quality analysis inventory results are more comparable to the Tier 2 Model results presented in the NPRM for the nationwide inventories than for the city-specific inventories. In comparing the two modeling methodologies, we consider differences between the air quality inventories and the Tier 2 Model to be the effect of local parameters on the county-specific modeling which could not be replicated by the Tier 2 Model.

The "air quality analysis" inventory estimates presented in Chapter 3 of the Tier 2 final rule RIA were therefore derived directly from county-specific inventories, by totaling the emissions from all counties in the 47 state analysis region (U.S. minus California, Alaska and Hawaii) in 1996, 2007 and 2030. The reported NOx and VOC results are the 47 state totals for a "ozone season day" were multiplied by 365, resulting in "annualized ozone season day" tons. The purpose of this metric is simply to present a comparison of inventory results under ozone season conditions; the air quality analysis itself used the actual seasonal results as input. SOx and PM_{10} estimates were based on the true annual results produced in the air quality analysis. For all pollutants, these results are shown in the Microsoft Excel worksheet entitled "FRMINV.XLS", under the heading "Air Quality Analysis Results".

The next step in the analysis was to generate estimates for years other than 1996, 2007 and 2010. We utilized the Tier 2 Model to derive results for these years, but modifications were required to the model to be consistent with the air quality analysis. Starting with the NPRM version of the model, we made three adjustments to reflect differences between the this model and the air quality analysis modeling : a) we removed the additive emissions adjustment which estimated the effects of emissions tampering, b) we revised the 47-state light-duty VMT estimate to match that used in the air quality analysis (using linear interpolation to generated estimates for

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[1] "Development of On-Highway Inventory Adjustment Factors Used in the Tier 2 Final Rule Air Quality Analysis", Memorandum from John Koupal to Docket A-97-10

[2] Koupal, "Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards", EPA Report No. EPA420-R-99-005, March 1999

years other than 1996, 2007 and 2030, and c) we ran the model under summertime conditions. This version of the Tier 2 Model is named "T2MODAQA.XLS"; it is operated identically to the NPRM version of the Tier 2 Model. Results from T2MODAQA.XLS are contained in FRMINV.XLS under the heading "T2MODAQA Raw Results", for each pollutant.

The next step in the analysis was to "normalize" the raw Tier 2 Model results so that they matched the actual air quality analysis results. As mentioned, we considered the difference between the two modeling approaches to be caused by better resolution of local inputs in the air quality work. Thus, we considered it appropriate to adjust the Tier 2 Model results in all years to account for the "local effects" observed in 1996, 2007 and 2030. The relative differences varied by year, vehicle class and baseline or control case. For NOx and SOx, we developed "locality adjustments" in 1996, 2007 and 2030 by dividing the air quality analysis results by the Tier 2 Model results for the three light-duty vehicle classes (LDV, LDT1/2 and LDT3/4). For in-between years we calculated the locality adjustment for each vehicle class through linear interpolation between 1996 and 2007, and 2007 and 2030. These adjustments were developed for the baseline and control cases, and are contained in the NOx and SOx worksheets of FRMINV.XLS under the heading "Locality Adjustments". The raw Tier 2 Model results by vehicle class were then multiplied by the appropriate locality adjustment in each year, resulting in our estimate of the air quality analysis inventories for all years. These are contained in FRMINV.XLS, under the heading "T2AQA Adjusted Results".

The generation of VOC and PM_{10} inventories followed a similar path, but required additional steps. VOC results from the air quality analysis were reported as total VOC, with no breakdown between the exhaust and evaporative portions. The Tier 2 Model was used to generated raw exhaust emissions results (FRMINV.XLS, VOC, "T2AQA Raw Exhaust Results"). Evaporative inventory results reported in the NPRM, adjusted to reflect summertime conditions, served as the raw evaporative results (FRMINV.XLS, VOC, "Raw Evaporative Results"). Locality adjustments were developed by dividing the air quality analysis total VOC results in 1996, 2007 and 2030 by the sum of the raw exhaust and evaporative results (by vehicle class) and interpolating to generate adjustments for in-between years. Raw exhaust and evaporative data were multiplied by the locality adjustments (FRMINV.XLS, VOC, "T2AQA Exhaust Adjusted Results", "Raw Evaporative Adjusted Results") and summed to result in our estimate of total VOC emissions in all years (FRMINV.XLS, VOC, "Total Adjusted Results").

PM_{10} results from the air quality analysis were reported including nonexhaust sources such as brake and tire wear, whereas we are primarily interested in assessing only direct exhaust PM_{10} emissions. The Tier 2 Model was used to generate direct exhaust PM_{10} in four categories: all diesel, gasoline LDV, gasoline LDT1/2 and gasoline LDT3/4 (FRMINV.XLS, PM_{10}, "T2AQA Raw Results"). Locality adjustments were developed for the diesel category simply by dividing the air quality analysis results by the raw Tier 2 Model results. For the gasoline categories, the additional step was taken of estimating the direct exhaust portion of the air quality analysis results. The exhaust proportion of total direct PM_{10} reported in the NPRM was 41 percent for the baseline case and 22 percent for the control case (Appendix A, NPRM Regulatory

Impact Analysis). These percentages were applied to the gasoline categories of the air quality analysis results, and divided by the raw Tier 2 Model results to derive the gasoline locality adjustments (FRMINV.XLS, PM10, "Locality Adjustments"). The locality adjustments were multiplied by the raw Tier 2 Model results to derive our estimate of direct exhaust PM_{10} emissions (FRMINV.XLS, PM10, "T2AQA Adjusted Direct Exhaust Results"). It should be noted that our approximation of the direct exhaust portion of total direct PM_{10} introduced a small error, so that when recombined our estimated direct exhaust reductions due to Tier 2 are approximately 3 to 5 percent higher than projected by the air quality analysis in 2007 and 2030.

We also analyzed the effects of increased diesel sales growth on PM_{10}. Since the proposal, we have derived more realistic growth assumptions based on work by A.D Little, Inc.; the resulting growth scenario is referred to as the A.D. Little "Most Likely" diesel growth scenario.[3] The original A.D. Little methodology presented sales penetrations for LDVs and LDTs in five-year increments; we filled in the missing years using linear interpolation, and assumed no growth in sales beyond 2015. For this analysis, we assumed that diesel LDT sales penetration would be distributed equally between the four truck classes. The resulting diesel sales penetrations are shown in Table 1.

[3]A.D. Little, Inc., "U.S. Light-Duty Dieselization Scenarios - Preliminary Study", Report to the American Petroluem Institute, July 1999

Table 1 - Diesel Sales Penetration Under Increased Growth Scenario		
Model Year	**LDV**	**LDT**
2001	0.1%	0.1%
2002	0.1%	1.5%
2003	0.1%	3.0%
2004	0.1%	4.5%
2005	0.3%	6.0%
2006	0.7%	8.2%
2007	1.0%	10.4%
2008	1.3%	12.6%
2009	1.7%	14.8%
2010	2.0%	17.0%
2011	3.4%	18.4%
2012	4.8%	19.8%
2013	6.2%	21.2%
2014	7.6%	22.6%
2015 and later	9.0%	24.0%

The Tier 2 Model was run with this sales penetration to generate raw direct emission results for the diesel and three gasoline categories (FRMINV.XLS, PM10, "T2AQA Raw Direct Exhaust Results - Increased Diesel Growth"). The gasoline results were then multiplied by the locality adjustments to derive the adjusted direct exhaust PM_{10} emissions for these categories. The diesel category was not multiplied by the locality adjustment, because the difference in diesel emissions between the base sales and increased sales cases was so large that applying these adjustments did not seem reasonable. We thus developed our "adjusted" direct exhaust PM_{10} emissions for the diesel category by adding the difference in the raw results between the increased sales and base sales cases to the adjusted base sales case. Our final estimates for direct exhaust PM_{10} emissions in all categories are shown in FRMINV.XLS, worksheet "PM10", under the heading "T2AQA Adjusted Direct Exhaust Results - Increased Diesel Growth".

For all pollutants, we estimated the phase-in of lower sulfur standards between 2004 and 2006. In 2004, average sulfur levels under the Tier 2 program will be reduced to 120 ppm. We developed estimates at this sulfur level through linear interpolation of Tier 2 Model results at

150 and 100 ppm. In 2005, average sulfur levels under the sulfur averaging, banking and trading (ABT) program were estimated at 90 ppm. We developed estimates at this sulfur level through linear interpolation of Tier 2 Model results at 100 and 30 ppm. Our 2006 estimates reflect the implementation of 30 ppm fuel. For this analysis reductions prior to 2004 were not modeled, although under the ABT program emission reduced sulfur levels could occur as early as 2000.

The Tier 2 vehicle program will also includes LDTs above 8,500 pounds used primarily for passenger purposes, known as "Medium-Duty Passenger Vehicles" (MDPVs).   We generated an estimate of NOx and VOC emissions reduced for these vehicles based directly on emission reductions projected for LDT3/4s.   Chapter IV of the Regulatory Impact Analysis estimates that in 1998, 70,000 of these vehicles were sold, versus 1,496,000 LDT3s and LDT4s. For our analysis we assumed that mileage accumulation rates would be the same between MDPVs and LDT4s, meaning that this sales split can be translated directly in to a split of vehicle miles traveled (VMT). To project the benefits of MDPVs, we multiplied our estimated reductions for LDT4s by 0.047, the ratio of projected MDPV VMT to LDT4 VMT, based on the above sales split. The results are shown in FRMINV.XLS, worksheets "NOx" and "VOC", under the heading "MDPV Reductions". It should be noted that our estimate of these reductions is likely very conservative, since baseline emissions for MDPVs are in fact much higher than LDT4s.

B. Derivation of Inventory Estimates Based on the Updated Tier 2 Model

Subsequent to the air quality analysis modeling, our Tier 2 Model was updated to reflect several new inputs stemming from a) our response to Tier 2 comments, b) new sulfur sensitivity data and c) alignment with methodologies planned for use in MOBILE6, as well as changes to the sulfur control program.. The updates to the model are summarized below:

- Tier 1 and later NOx emission rates were updated to reflect a significantly larger sample of vehicles certified to the 0.4 gram/mile NOx standard.
- Tier 1 and later HC emission rates were updated to reflect corrections to the estimated frequency of high-emitting vehicles.
- Sulfur effects for LEVs were increased significantly in response to new data showing that the effect of sulfur on emissions is much larger when a vehicle operates on high sulfur fuel for a few thousand miles.
- Sulfur irreversibility was accounted for. This effect results when vehicles sustain permanent catalyst degradation from exposure to sulfur levels higher than what they typically operate on.
- Off-cycle and air conditioning emissions were estimated in a manner more consistent with MOBILE6.
- In-use activity elements such as vehicle speed, roadway type, and trip activity are handled in a manner more consist with MOBILE6
- MOBILE6 temperature corrections were applied to model a typical ozone season day.
- The Tier 2/Sulfur control case reflects the final Tier 2 sulfur program, including

the effects of Averaging, Banking and Trading (ABT), special provisions for small refiners through the SBREFA program, and the geographic phase-in provisions of the final rule.

With these updates, the Tier 2 Model now includes many of the key exhaust elements planned for MOBILE6, and is the most up-to-date tool available for assessing trends in nationwide light-duty exhaust emissions and the emission reductions gained from the Tier 2/Sulfur program. Overall, the updated model indicates that NOx and exhaust VOC emissions without Tier 2/Sulfur control will be substantially higher than originally projected either in the proposal or by the air quality analysis modeling, particularly for NOx. The updated model only projects emissions for gasoline light-duty vehicles and trucks; our most current estimates of emissions from diesel light-duty vehicles and trucks are contained in T2MODAQA.XLS.

The magnitude of change to the modeling inputs required by these updates, particular sulfur irreversibility, lead to the development of a second-generation Tier 2 Model. This model is entitled "T2MODFRM.XLS", located in the Tier 2 Docket. This model is operated as a stand-alone model, unlike the NPRM version of the Tier 2 Model. Several separate files serve as "final emission rate generators", however, which are used to develop inputs to the updated model. FRMFER.XLS was used for the generation of Tier 1 and later emission rates; pre-Tier 1 emission rates were generated by PT1FRVNX (LDV NOx), PT1FRTNX (LDT NOx), PT1FRVHC (LDV Exhaust HC), and PT1FRTHC (LDT Exhaust HC). These files are referred to herein as the FER generator spreadsheets.

The purpose of this document is to focus mainly on the updates to the Tier 2 Model. Many of the methodologies for generating emissions inventory estimates with the model have not changed, and are not detailed here; a more comprehensive treatment of these issues can be found in EPA Report EPA420-R-99-005, "Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards", published with the NPRM and available in the Tier 2 Docket. This document is referred to as the "NPRM Light-Duty Report" herein. Many of the updated methodologies and inputs are presented more thoroughly in separate reports and/or regulatory documents (all in the Tier 2 Docket), as noted. The reader will need to reference these documents for a full presentation of the updated inputs, and to fully understand their origin.

1 Generation of Updated Model Inputs

1.1 Basic Emission Rates

Running and start NOx basic emission rates for Tier 1 and later LDVs and LDTs have been updated according to revisions planned for MOBILE6, as detailed in Draft Final MOBILE6

Report Number M6.EXH.007.[4] Emitter fractions (the frequency of high emitters in the fleet as a function of age) have been revised for both NOx and HC. The updated emission rates and emitter fractions are presented in full in M6.EXH.007. Emission rates for the Tier 2 standards (final and interim) were derived based on the Tier 1 emission rates using the methodology outlined in M6.EXH.007 and the NPRM Light-Duty Report. The Tier 2 emission rates have been updated to reflect the changes to the Tier 1 and later emission rates. The updated Tier 2 basic emission rates are shown in Tables 2 and 3.

Table 2 - Tier 2 NOx Basic Emission Rates

Vehicle Class	Standard Class	50/120K Standard (g/mi)	Mode	"Normal" BER (g/mi)		"High" BER (g/mi)	"Repaired" BER Cap (g/mi)
				ZML	DR		
LDV/T1	**Tier 2**	0.05/0.07	FTP	0.019	0.004	0.73	0.075
			Running	0.017	0.003	0.65	0.068
			Start (grams)	0.026	0.005	1.00	0.103
LDT2	**Interim**	0.2/0.3	SAME AS LDV/T1 LEV (M6.EXH.007)				
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				
LDT3	**Interim A**	0.4/0.6	SAME AS LDV/T1 TIER 1 (M6.EXH.007)				
	Interim B	0.14/0.20	FTP	0.054	0.010	0.87	0.210
			Running	0.048	0.009	0.78	0.189
			Start (grams)	0.073	0.014	1.19	0.288
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				
LDT4	**Interim A**	0.4/0.6	SAME AS LDV/T1 TIER 1 (M6.EXH.007)				
	Interim B	0.14/0.20	SAME AS LDT3 INTERIM B				
	Tier 2	0.05/0.07	SAME AS LDV/T1 TIER 2				

[4]Koupal and Glover, "Determination of NOx and HC Basic Emission Rates, OBD and I/M Effects for Tier 1 and Later LDVs and LDTs", Draft Final Report M6.EXH.007, December 1999

Table 3 - Tier 2 NMOG Basic Emission Rates							
Vehicle Class	**Standard Class**	**50/120K Standard (g/mi)**	**Mode**	**"Normal" BER (g/mi)**		**"High" BER (g/mi)**	**"Repaired" BER Cap (g/mi)**
				ZML	**DR**		
LDV/T1	**Tier 2**	0.075/0.09	SAME AS LDV/T1 LEV (M6.EXH.007)				
LDT2	**Interim/Tier 2**	0.2/0.3	SAME AS LDV/T1 LEV (M6.EXH.007)				
LDT3	**Interim A**	0.16/0.23	SAME AS LDT3 LEV (M6.EXH.007)				
	Interim B	0.125/0.156	FTP	0.049	0.057	1.35	0.188
			Running	0.011	0.013	0.31	0.043
			Start	0.537	0.624	14.90	2.063
	Tier 2	0.05/0.07	SAME AS LDV/T1 LEV (M6.EXH.007)				
LDT4	**Interim A**	0.16/0.23	SAME AS LDT3 LEV (M6.EXH.007)				
	Interim B	0.125/0.156	SAME AS LDT3 INTERIM B				
	Tier 2	0.075/0.09	SAME AS LDV/T1 LEV (M6.EXH.007)				

The Repaired Emitter "Cap" reflects an updated to how vehicles which have undergone a repair in response to the OBD diagnosis (M6.EXH.007). These BER caps are only relevant at high mileages, under the revised MOBILE6 approach for estimating OBD repair benefit; prior to these mileages, emissions from repaired vehicles are set equal to normal emitters.

1.2 Off-Cycle

For the updated Tier 2 Model, emissions due to speed and acceleration rates in excess of those found on the conventional FTP have been revised in a manner consistent with that planned for MOBILE6.[5,6] MOBILE6 will apply two correction factors to the running BERs presented in Tables 2 and 3. A multiplicative speed correction factor (SCF) will be applied to running exhaust emissions to account for differences in emissions across speed and roadway type, relative to emissions at the average speed of the LA4 (19.6). However, these speed correction factors were developed from emission test cycles which are more aggressive than the LA4, meaning that the implied emissions level on the speed correction curve at 19.6 mph is higher than on the LA4 itself. The point where the SCF equals 1.0 is at the 19.6 mph point on the freeway curve. An "off-cycle" adjustment was therefore developed to correct the LA4-based running BERs to the 19.6 mph point on the freeway speed correction curve, from which the appropriate speed-correction could be applied. To accomplish this, the off-cycle correction was derived by comparing running LA4 emissions to an emission test cycle with comparable speed used in the generation of the freeway speed correction factors - a cycle referred to as "Freeway Level Of Service (LOS) F". The off-cycle correction factor is a function of base emissions, relating the difference in emissions between the freeway LOS F cycle and the LA4 to base running (LA4) emissions. The equations used for generating this off-cycle adjustment are presented in draft MOBILE6 report M6.SPD.005.

The benefits of the Supplemental Federal Test Procedure (SFTP) rulemaking are applied to the off-cycle correction as a percent reduction. These benefits have been updated since the proposal, and are presented in M6.SPD.005. Because the SFTP standards being proposed for Tier 2 are functionally equivalent to ARB's current LEV standards, aggressive driving emissions are assumed to remain unchanged between SFTP-controlled LEVs and Tier 2 vehicles. Tier 2 LDVs and LDTs are therefore modeled as having the same additive aggressive driving adjustment as SFTP-controlled LEVs, by vehicle class.

1.3 Speed and Roadway Type

The incorporation of speed and roadway type effects into the updated Tier 2 Model is a

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[5] Gilmore, et al., "Determination of Off-Cycle Emissions and Supplemental FTP Control Modeling in MOBILE6", Draft MOBILE6 Report M6.SPD.005, December 1999.

[6] Brzezinski, et al., "Facility-Specific Speed Correction Factors", Draft MOBILE6 Report M6.SPD.002, August 1999

significant change from the NPRM version of the Tier 2 Model, and is a major contributor to the difference in emission levels between the two models. The method used to account for off-cycle and speed differences in the NPRM version of the model relied on emissions results at a single average speed (24.6 mph). Accounting for emissions over a more representative distribution of speeds and roadway types (as will be done in MOBILE6) results in significantly higher estimates of running emissions, particularly for NOx..

The adjustments made for roadway type and average speed (speed correction factors, or SCFs) were calculated based on the methods and values found in the draft report, “Facility Specific Speed Correction Factors,” (EPA420-P-99-002, M6.SPD.002) and the draft report, “Development of Methodology for Estimating VMT Weighting by Facility Type,” (EPA420-P-99-006, M6.SPD.003). This information was used to compute a composite national average speed correction factor reflecting average speed and VMT distribution by roadway type, which was applied to the emission rates calculated in the FER generator spreadsheets.

The purpose of SCFs is to account for the effects of driving behavior on different roadway types and different levels of congestion at average speeds other than 19.6 mph. Running emission rates which were adjusted to reflect the off-cycle correction discussed in the previous section were multiplied by the SCF to account for these effects. For MOBILE6, SCF curves were developed for three discrete running emission levels, known as “Level 1", “Level 2", and “Level 3" (Table 4). When modeling a running emission value between these predetermined emission levels, SCFs where determined by interpolating between these curves. Since emission rates change with mileage, a composite SCF was calculated separately for each mileage level in the FER generator spreadsheets, as will be done in MOBILE6.

The calculation of SCFs for this analysis is contained in the spreadsheet “DAILYWGT.XLS”. A national average SCF was developed by combining the disaggregated SCFs (by roadway type and speed) together based on a national average VMT distribution. There are four basic roadway types in MOBILE6: freeways, arterials, local roadways and freeway ramps. The freeway and arterial/collector roadways have a distribution of VMT over a range of 14 speed “bins,” ranging from 5 to 65 mph in increments of 5 mph. For this analysis, a SCF was calculated for each speed bin and then weighted together by the daily VMT in each speed bin, resulting in a daily SCF for freeways and arterial/collectors. The freeway and arterial/collector SCFs were then weighted together with the freeway ramp and local roadway SCFs using the VMT distribution by roadway type to give a single composite daily SCF for each pollutant and emission level. The final SCFs by roadway type are presented in Table 4, along with the national average composite SCF based on the VMT distribution of the four roadway types.

Table 4 - National Average Speed Correction Factors			
	VMT Weight	**HC**	**NOx**
Level 1 Emissions (g/mi)		**0.020**	**0.191**
Composite SCF	**1.0000**	**1.4973**	**1.3058**
Freeway SCF	0.3420	1.5900	1.3443
Arterial SCF	0.4978	1.2145	1.1716
Local SCF	0.1304	1.9000	1.6283
Freeway Ramp SCF	0.0298	3.4000	1.6963
Level 2 Emissions (g/mi)		**0.157**	**0.591**
Composite SCF	**1.0000**	**0.9837**	**1.1570**
Freeway SCF	0.3420	0.7777	1.1335
Arterial SCF	0.4978	0.8769	1.0656
Local SCF	0.1304	1.6369	1.4044
Freeway Ramp SCF	0.0298	2.2739	1.8714
Level 3 Emissions (g/mi)		**2.945**	**3.245**
Composite SCF	**1.0000**	**0.7587**	**1.0426**
Freeway SCF	0.3420	0.6437	1.0209
Arterial SCF	0.4978	0.7370	1.0178
Local SCF	0.1304	1.1019	1.1510
Freeway Ramp SCF	0.0298	0.9396	1.2320

As mentioned, the application of the appropriate SCF depends on how the running emission level compares to the predetermined emission levels. Emission rates at or higher than Level 3 use the Level 3 SCF; emission rates at or below Level 1 use the Level 1 SCF. SCFs are derived from emission rates in between Level 1 and Level 3 through linear interpolation

The FER generator spreadhsheets contain the SCFs applied to each vehicle and standard class by vehicle mileage using the methodology outlined above. Most running emission rates for LEV and Tier 2 normal-emitter vehicles are near or below the Level 1 emissions threshold of 0.191 g/mi. This means that for these vehicles NOx running emission rates were increased by roughly 30 percent by the application of the SCF. It is important to note that these SCFs were applied to both pre-SFTP and SFTP-compliant vehicles. Because SFTP benefit is applied in the off-cycle adjustment, overall emissions after application of the SCF will be lower than for pre-SFTP vehicles; however, our analysis of vehicles with very low off-cycle emissions suggests that this magnitude of SCF is still appropriate for SFTP-compliant vehicles (M6.SPD.005).

1.4 Air Conditioning

The approach for estimating air conditioning emissions in the updated Tier 2 Model has also been revised since the NPRM.[7] The updated approach reflects changes to the methodology planned for MOBILE6, but required some simplification because the MOBILE6 air conditioning equations vary by speed and roadway type, and could not by fully replicated in the Tier 2 Model. Because the MOBILE6 air conditioning equations represent excess air conditioning emissions at extreme temperature and humidity levels, the air conditioning adjustment derived from these data represents full air conditioning load, termed "full-usage".

Two NOx "full-usage" air conditioning adjustment equation were developed, one each for LDVs and LDTs. Within these vehicle classes, the equations were applied across standard and emitter level. The use of one equation each for LDVs and LDTs is a simplification from MOBILE6, for which air conditioning emissions will be calculated on the four roadway types at five mph speed increments (Freeway and Arterial only). Simpified equations were developed for the Tier 2 Model by setting the average speed equal to 34 mph in the MOBILE6 equations; this is not the actual in-use average speed, but the speed which results in a correction factor of comparable magnitude to the MOBILE6 approach (FRMFER.XLS, "M6 CORRECTIONS"). The resulting equations are as follows:

*(1) NOx "Full Usage" A/C Adjustment for LDV/LDT1s (g/mi) = K*Log(ACOFF +1)*

Where:

K = 1.351 for LDVs, 0.752 for LDTs
*ACOFF = (Running emissions adjusted for Off-Cycle and Speed) * (Temperature Correction)*

MOBILE6 will also estimate air conditioning emissions for exhaust HC. For the updated Tier 2 Model, a linear equation was developed which combined the MOBILE6 full-usage equation for Freeway, Arterial and Ramp roadways at the composite average speed on these cycles (33.4 mph) as the intercept, and the MOBILE6 full-usage equation for Freeway, Arterial and Ramp roadways at the average speed of the Local cycle (12.9 mph), whose MOBILE6 equation is a function of base emissions) as the slope. The resulting equation is as follows:

*(2) HC "Full Usage" A/C Adjustment for LDV/LDT1s (g/mi) = 0.0388 + 0.0151*ACOFF*

Where:

*ACOFF = (Running emissions adjusted for Off-Cycle and Speed) * (Temperature Correction)*

In order to reflect air conditioning emissions under more typical summertime conditions, the full-usage air conditioning adjustments from Equations (1) and (2) were reduced according to

[7] Koupal and Kremer, "Air Conditioning Correction Factors in MOBILE6", Draft Final MOBILE6 Report M6.ACE.002, December 1999

the "heat index" methodology planned for MOBILE6.[8] This methodology was identical to that detailed in the NPRM Light-Duty Report, and resulted in an air conditioning demand factor of 0.68 for a typical ozone season day.

Air conditioning emission reductions resulting from the SFTP requirement were handled by applying percent reductions to the product of Equations (1) or (2) and the air conditioning demand factor. The percent reductions and the methodology used to derived them are detailed in M6.SPD.005.

1.5 Trip Activity

Emission rates used in the NPRM version of the Tier 2 Model were based on soak time and trip length characteristics carried over from the FTP. The FTP includes one soak period of duration 12 hours and one of duration ten minutes, and assumes that all trips are 7.5 miles long. MOBILE6 will account for more recent in-use data which suggests that soak times are more evenly distributed, and the average trip length is closer to four miles (meaning there are more starts per mile, and hence more start emissions per mile, than contained in the FTP).

The updated distribution of soak times was estimated in the Tier 2 Model based on MOBILE6 methodologies as presented in two draft reports, "Determination of Start Emissions as a Function of Mileage and Soak Time for 1981 - 1993 Model Year Light Duty Vehicles," (M6.STE.003) and "Soak Length Activity Factors for Start Emissions," (M6.FLT.003). Because MOBILE6 will model the distribution of soak times for each hour of the day and the number of engine starts per vehicle per day, a simplified approach was necessary for the Tier 2 Model. This took the form of a single multiplicative adjustment which, when applied to the final emission rates for starts, estimated the emissions from the in-use soak time distribution.

The soak time adjustments were developed by generating a weighted average soak time based on weekday soak distributions from M6.FLT.003. Multiplicative factors which represented the fraction of cold start emissions which would result from starts after this average soak time were then computed; the resulting factors are 0.49 for HC and 0.61 for NOx. These soak time adjustment were applied to the start FERs in the FER generator spreadsheets to account for a more representative distribution of soak times. The derivation of these estimates is contained in the files "SOAKMIN.XLS" and "SOAKDIS.XLS"

Using the annual mileage accumulation and age distribution for cars (from draft report M6.FLT.007, "Fleet Characterization Data for MOBILE6") and the average number of engine starts per weekday for cars (7.28) presented in M6.FLT.003, the average amount of miles per engine start was calculated to be 4.05 miles per trip ("SOAKMIN.XLS"). This implies a significantly larger share of starts (and start emissions) per trip than the FTP. Incorporating this

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[8] Koupal, "Air Conditioning Activity Effects in MOBILE6", Draft MOBILE6 Report M6.ACE.001, January 1998

factor in the updated Tier 2 Model thus served to increase overall emissons, particularly for HC.

1.6 Temperature Corrections

Temperature corrections planned for MOBILE6 were used to adjust the emission rates to reflect a temperature of 91 degrees, the weighted average temperature computed by MOBILE5 for a typical ozone day (reflecting a diurnal of 72 to 96 degrees). The multiplicative temperature correction used in the updated Tier 2 Model are shown in Table 5:

Table 5 - Temperature Correction Factors

	Model Years	Running	Start
NOx	< 1982/1985*	1.032	1.0
	< 1993	1.032	1.0
	Tier 1 +	1.032	1.0
HC	< 1982/1985*	1.103	1.088
	< 1993	1.146	1.146
	Tier 1 +	1.146	1.069

* 1982 for LDVs, 1985 for LDTs

1.7 Calculation of Final Emission Rates at 30 ppm Sulfur

Running and start emission levels for normal emitters, high emitters and repaired emitters were adjusted to account for off-cycle, speed, air conditioning, temperature and non-sulfur fuel effects (discussed in the NPRM Light-Duty Report) at the end of each year in a vehicle's life, according to Equations (3) and (4):

$$(3)\ Running\ Emissions_{EM,AGE}\ (g/mi) = ((R_{EM,AGE} + OC_{EM,AGE}) * SCF_{EM,AGE} * T_{EM}) + AC_{EM,AGE})* N_{EM}$$

$$(4)\ Start\ Emissions_{EM,AGE}\ (grams) = S_{EM,AGE} * N_{EM}$$

Where:

EM = Emitter Class (Normal, High or Repaired)
AGE = Vehicle age, from one to 25 years
R = Running BER, as a function of the cumulative mileage at the end of year AGE
S = Running BER, as a function of the cumulative mileage at the end of year AGE
OC = off-cycle adjustment, in g/mi
SP = Speed Correction Factor
T = Temperature Correction Factor (91 °, typical summer day)

AC = Typical summer day air conditioning adjustment, in g/mi
N = Non-sulfur fuel adjustment factor

Age-based start and running emission levels as calculated in the preceding equations were then combined into age-based composite emission levels according to Equation (5):

$$(5)\ Composite\ Emissions_{EM,AGE}\ (g/mi) = (RUN_{EM,AGE} * 4.05 + ST_{EM,AGE} * SOAK) / 4.05$$

Where:

EM = Emitter Class (Normal, High or Repaired)
AGE = Vehicle age, from one to 25 years
RUN = Running emissions from Equation (6), grams/mile
ST = Start emissions from Equation (7), grams
SOAK = Activity-weighted soak length factor: 0.61 for NOx, 0.49 for HC
4.05 = Average miles per trip

For Tier 1 and later normal emitters, a linear regression was fit through the results of Equation (5) to generate a final emission rate at 30 ppm consisting of a zero-mile level (ZML) and deterioration rate (DR). High emitter and repaired emitter cap FERs were modeled as constants. Results for Tier 1 and later normal, high and repaired emitters at 30 ppm are contained in T2MODFRM.XLS, worksheet "LOOKUP".

FERs for pre-Tier 1 LDVs and LDTs were expressed as a ZML and DR which included the effects of normal emitters, high emitters, and their relative frequency as a function of mileage. The method for deriving these FERs is discussed in the NPRM Light-Duty Report. The updated FERs are presented in the pre-Tier 1 FER generator spreadsheets, under the worksheet "FER RESULTS".

1.8 Fuel Sulfur Effects

The primary revision to fuel sulfur effects in the updated Tier 2 Model were the incorporation of "Long-Term Exposure" effects, and the accounting for sulfur irreversibility (discussed later). "Short-Term" sulfur effects generated for the NPRM Tier 2 Model have not been revised, and reflect our current estimate of the emission increase which would result from minimal exposure (i.e., a single tank of gas) to high sulfur levels. These are shown in Table 6.

Table 6 - FTP Emissions Increase Due To Fuel Sulfur, Relative to 30 ppm (Short-Term Exposure)									
Std	**Vehicle Class**	**NOx**				**HC***			
		Normal Emitters		**High Emitters**		**Normal Emitters**		**High Emitters**	
		150 ppm	**330 ppm**	**150 ppm**	**330 ppm**	**150 ppm**	**330 ppm**	**150 ppm**	**330 ppm**
Tier 0	**All**	5.1%	7.7%	3.7%	9.6%	9.3%	14.1%	0.4%	1.1%
Tier 1	**All**	3.9%	10.0%	2.3%	6.0%	9.1%	24.2%	0.4%	1.1%
LEV	**LDV**	76.8%	133.7%	46.1%	80.2%	25.3%	39.9%	0.4%	1.1%
	LDT2/3/4	26.5%	42.0%	15.9%	25.2%	15.5%	24.0%	0.4%	1.1%
Tier 2	**LDT2 Interim “A”**	Same as LDV LEV							
	LDT3 Interim “A”	Same as LDT2/3/4 LEV							
	LDT4 Interim “A”	Same as LDT2/3/4 LEV							
	LDT3/4 Interim “B”	Same as LDV LEV							
	All Final	Same as LDV LEV							

*NMHC Adjustments

Subsequent to the proposal, data has been generated which indicates that emissions from LEVs exposed to higher sulfur levels for durations over a few thousand were significantly higher than emissions on a vehicle exposed to the same sulfur level for a short duration.[9] Our analysis of these data indicate that on average, long-term exposure to a given sulfur level increases the emissions sensitivity of for LEV LDVs and LDTs at a given sulfur level by 47 percent for NOx, and 149 percent for HC. Long-term sulfur exposure effects were therefore calculated by increasing the LEV adjustments shown in Table 6 by these percentages. The results are shown in Table 7.

[9]“Short-Term Versus Long-Term Sulfur Sensitivity”, Memorandum from Linc Wehrly for Docket A-97-10.

Table 7 - FTP Emissions Increase Due To Fuel Sulfur, Relative to 30 ppm (Long-Term Exposure)									
Std	**Vehicle Class**	**NOx**				**HC***			
		Normal Emitters		**High Emitters**		**Normal Emitters**		**High Emitters**	
		150 ppm	**330 ppm**	**150 ppm**	**330 ppm**	**150 ppm**	**330 ppm**	**150 ppm**	**330 ppm**
Tier 0	**All**	5.1%	7.7%	3.7%	9.6%	9.3%	14.1%	0.4%	1.1%
Tier 1	**All**	3.9%	10.0%	2.3%	6.0%	9.1%	24.2%	0.4%	1.1%
LEV	**LDV**	112.9%	196.5%	67.8%	117.9%	63.0%	99.4%	1.0%	2.7%
	LDT2/3/4	40.0%	61.7%	23.4%	37.0%	38.6%	59.8%	1.0%	2.7%
Tier 2	**LDT2 Interim "A"**	Same as LDV LEV							
	LDT3 Interim "A"	Same as LDT2/3/4 LEV							
	LDT4 Interim "A"	Same as LDT2/3/4 LEV							
	LDT3/4 Interim "B"	Same as LDV LEV							
	All Final	Same as LDV LEV							

*NMHC Adjustments

2 Methodology for Generating Inventory Estimates

2.1 Fleetwide Emission Factors for Pre-Tier 1 LDVs and LDTs

Emissions from pre-Tier 1 LDVs and LDTs[10] and were estimated using a lookup table which contained the fleetwide emission factor for these years , by calendar year. These lookup tables were generated by 1) updating the NOXFER.XLS and NMHCFER.XLS inputs files to reflect our updated approach to off-cycle, speed, air conditioning, trip activity and temperature correction discussed above (the updated versions are named NOXFRM.XLS and NMHCFRM.XLS, located in the Tier 2 Docket), and 2) executing the air quality analysis version of the Tier 2 Model (T2AQA.XLS) using these updated input files in a manner which isolated the effects of the pre-Tier 1 vehicles. The model was run for four combinations: IM/RFG, IM/CG, No IM/RFG and No IM/CG, and the results weighted together based on the summertime 47-State weightings presented in the NPRM Light-Duty Report. The model was run at 30, 100, 150, 300 and 330 ppm; once the 47-state results were generated as described, a linear regression was fit across these sulfur levels in each calendar year so that the fleetwide emission factors for pre-Tier 1 vehicles could be estimated at any sulfur level, based on the following formula:

[10]Pre-Tier 1 was defined as 1994 and earlier for LDVs and LDT1/2s and 1995 and earlier LDT3/4s. The effect of this simplication are immaterial on the estimate of baseline and control emissions beyond 2000.

$$(6)\ PRET1_{YEAR} = Intercept_{YEAR} + Slope_{YEAR} * Sulfur$$

Where:

$PRET1_{YEAR}$ = *Fleetwide emission factor for pre-Tier 1 vehicles in calendar year YEAR*
$Intercept_{YEAR}$ = *Emission factor at 30 ppm*
Sulfur = Sulfur level, in ppm

The coefficients for these regression equations are presented in Tables 8 and 9.

Table 8 - Regression Equations for Determining Pre-Tier 1 NOx Emission Factors

Calendar Year	LDV		LDT1/2		LDT3/4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
2000	0.943	2.46E-04	0.835	2.02E-04	1.345	3.37E-04
2001	0.822	2.15E-04	0.703	1.70E-04	1.180	2.97E-04
2002	0.704	1.84E-04	0.581	1.41E-04	1.033	2.61E-04
2003	0.591	1.55E-04	0.472	1.15E-04	0.840	2.16E-04
2004	0.485	1.27E-04	0.378	9.25E-05	0.735	1.89E-04
2005	0.386	1.02E-04	0.290	7.01E-05	0.607	1.52E-04
2006	0.303	7.99E-05	0.226	5.45E-05	0.528	1.33E-04
2007	0.234	6.17E-05	0.174	4.22E-05	0.461	1.16E-04
2008	0.180	4.76E-05	0.129	3.10E-05	0.384	9.61E-05
2009	0.138	3.66E-05	0.099	2.39E-05	0.335	8.43E-05
2010	0.105	2.78E-05	0.078	1.89E-05	0.295	7.50E-05
2011	0.080	2.13E-05	0.063	1.54E-05	0.257	6.62E-05
2012	0.061	1.59E-05	0.052	1.23E-05	0.223	5.75E-05
2013	0.046	1.21E-05	0.044	1.06E-05	0.193	4.98E-05
2014	0.035	9.11E-06	0.038	8.99E-06	0.167	4.30E-05
2015	0.026	6.86E-06	0.032	7.62E-06	0.143	3.71E-05
2016	0.020	5.13E-06	0.027	6.44E-06	0.123	3.19E-05
2017	0.015	3.81E-06	0.023	5.41E-06	0.106	2.73E-05
2018	0.009	2.41E-06	0.018	4.39E-06	0.090	2.34E-05
2019	0.000	0.00E+00	0.000	0.00E+00	0.000	0.00E+00

Table 9 - Regression Equations for Determining Pre-Tier 1 Exhaust HC Emission Factors						
Calendar Year	LDV		LDT1/2		LDT3/4	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
2000	0.581	9.77E-05	0.700	1.31E-04	1.586	2.65E-04
2001	0.495	8.56E-05	0.588	1.10E-04	1.414	2.25E-04
2002	0.416	7.36E-05	0.486	9.09E-05	1.256	1.90E-04
2003	0.344	6.21E-05	0.394	7.01E-05	1.040	6.68E-05
2004	0.273	5.10E-05	0.318	5.54E-05	0.920	5.64E-05
2005	0.213	4.18E-05	0.236	4.81E-05	0.729	7.07E-05
2006	0.166	3.24E-05	0.187	3.68E-05	0.640	5.97E-05
2007	0.127	2.48E-05	0.149	2.79E-05	0.564	5.07E-05
2008	0.097	1.90E-05	0.105	1.95E-05	0.447	3.75E-05
2009	0.074	1.45E-05	0.082	1.48E-05	0.392	3.24E-05
2010	0.056	1.12E-05	0.066	1.17E-05	0.344	2.92E-05
2011	0.042	8.46E-06	0.053	9.62E-06	0.297	2.62E-05
2012	0.030	6.57E-06	0.038	9.11E-06	0.260	2.23E-05
2013	0.023	4.95E-06	0.032	7.79E-06	0.226	1.90E-05
2014	0.017	3.74E-06	0.027	6.71E-06	0.196	1.62E-05
2015	0.013	2.80E-06	0.023	5.83E-06	0.169	1.38E-05
2016	0.010	2.09E-06	0.019	4.75E-06	0.146	1.17E-05
2017	0.007	1.55E-06	0.015	3.99E-06	0.125	9.97E-06
2018	0.005	1.13E-06	0.011	2.84E-06	0.108	8.49E-06
2019	0.000	0.00E+00	0.000	0.00E+00	0.000	0.00E+00

2.2 By-Model Year FERs for Tier 1 and Later LDVs and LDTs

By-model year FERs for Tier 1 and later LDVs and LDTs were developed to account for the phase-in schedules of the Tier 1, NLEV and SFTP requirements. Because these requirements form the basis of vehicle control which would remain in place in the absence of Tier 2 control, they define the baseline case for this analysis from the vehicle program perspective. The generation of by-model FERs reflecting these phase-in schedules was handled according to the methodology described in the NPRM Light-Duty Report. To simplify the updated Tier 2 Model, we used phase-in schedules which approximated the actual phase-in for some cases (Table 10). For these cases, the actual phase-in schedules are presented in parentheses next to our approximated phase-in. The effect of this simplification on pre- and post-control emissions is negligible, particularly in for 2007 and beyond.

Table 10 - Tier 2 Model Phase-In Schedules for Tier 1, NLEV, SFTP

Model Year	Tier 1		NLEV (LDV/T1/T2 Only)		SFTP	
	LDV/T1/T2	LDT3/4	TLEV[11]	LEV	LDV/T1/T2	LDT3/4
1994	0 (40)					
1995	100 (80)					
1996	100	100 (50)				
1997		100				
1998						
1999			0 (60)*	40*		
2000			0 (40)*	60*		
2001				100	25	
2002					50	0 (40)
2003			* Ozone Transport Region		85	100 (80)
2004					100	100

The regional weighting aspect of NLEV was accounted for using the OTR population weightings were 0.29 for the OTR region and 0.71 for the non-OTR region. These weighting factors were only relevant to the FERs generated in model years 1999 and 2000, since these are the only years for which the OTR has a unique NLEV program. This resulted in a 47-state LEV "phase-in" of 11.6 in 1999 and 17.4 in 2000. Beginning in 2001, NLEV was assumed for this

[11] TLEV standards are the same as Tier 1 for NOx; hence, our approximated phase-in schedule would only affect our estimate of HC emissions.

analysis to apply to the entire 47-state region.[12]

By-model year FERs which reflected the Tier 2 vehicle program were developed in a manner identical to that outlined in the NPRM Light-Duty Report, except that for the updated model FERs were generate separately for all of the interim and final standard classes (the NPRM model relied on interpolation to generate FERs for some of the interim LDT standards). This included the estimation of a "sequential" phase-in, which assumes that manufacturers will comply with the required phase-in schedules by phasing in lighter vehicles before heavier vehicles.

2.3 Sulfur Irreversibility

The incorporation of sulfur irreversibility was new to the Tier 2 Model, and required a significant structural change to the model itself. Sulfur irreversibility is characterized as the inability of a vehicle's catalyst to fully recover from exposure to sulfur levels higher than what the vehicle normally operates on. The emissions performance of the vehicle is permanently affected by the exposure to higher sulfur fuel, and must be modeled accordingly. We assume this will only occur for vehicles which comply with the SFTP requirement, as discussed in Appendix B of the RIA. For our analysis, we assumed that exposure to higher sulfur fuel comes about in four basic ways: 1) seasonally, in which a vehicle in an RFG area is exposed to higher sulfur fuel in the winter months; 2) categorically, in which a vehicle is exposed to higher sulfur fuel across different fuel categories; 3) temporally, in which a vehicle was exposed to sulfur levels prior to the implementation of a control program such as Tier 2; and 4) due to normal variation in sulfur levels that occurs within a fuel category.

A comprehensive model of sulfur irreversibility would need to account for the range of sulfur levels that a vehicle has been exposed to in its lifetime through any of these four means. This model would approach that of a Monte Carlo simulation to predict a vehicle's travel and the variability of sulfur levels within a region. A model of this level of sophistication could not be realistically developed for this analysis. Our approach to modeling sulfur irreversibility, outlined in the following sections, therefore makes a number of simplifying assumptions.

2.3.1 Fuel Categories

Our updated model accounts for the small refiner and geographic phase-in provisions contained in the Tier 2 fuel program. These provisions are termed "SBREFA", after the program which gives certain small refiners a longer time to comply with the program, and "GPI", to account for refineries participating in the geographic phase-in provision of the Tier 2 rule. Based on the definitions of East (API Region) and West (outside the API Region) provided by

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[12] Four states (New York, Massachusetts, Maine, and Vermont) have adopted California's vehicle program rather than NLEV. The impact of this was not modeled; rather, NLEV was assumed to apply across the entire 49-state region.

API in their proposed fuel control program,[13] our model divides the fuel produced in the 47-state region into seven "fuel categories", as shown in Table 11.

Table 11 - Fuel Categories in Updated Tier 2 Model	
Fuel Category	**Description**
East CG	Conventional gasoline areas in the east
RFG	Reformulated Gasoline areas (all in the east)
East SBREFA	Fuel produced by SBREFA refiners in the east
East GPI	Fuel produced by eastern refiners under the geographic phase-in
West CG	Conventional gasoline areas in the west
West SBREFA	Fuel produced by SBREFA refiners in the west
West GPI	Fuel produced by western refiners under the geographic phase-in

2.3.2 Sulfur Levels With and Without Tier 2

The next step in the analysis is to define the sulfur levels (average and cap) for each fuel category by calendar year for the baseline and control scenarios (Tables 12 and 13). Our baseline sulfur levels reflect our analysis of more recent in-use fuel data. Our control case sulfur levels account for the SBREFA, geographic phase-in and averaging, banking and trading (ABT) provisions in the Tier 2 rule.

Focusing on the projection of the average sulfur levels first, the sulfur levels in 2000 were determined from an assessment of refiner's certification records from 1998. Outside of California, gasoline sulfur levels averaged 268 ppm in 1998. As discussed in the Draft RIA, EPA projects that RFG will average roughly 150 ppm beginning in 2000 in order to meet the Phase 2 RFG NOx performance specification. Comments from a number of oil refiners and NPRA indicated that refiners would not reduce the sulfur of their total gasoline pool in order to meet the Phase 2 RFG NOx performance specification in 2000, but would shift sulfur from RFG to CG in the summer and vice versa in the winter. The average sulfur level of RFG in 1998 was 207 ppm. Because this level is fairly close to the 150 ppm RFG target, it is quite conceivable that refiners could perform the sulfur shift outlined in the comments to the proposed rule. Assuming that the sulfur level of summer RFG was reduced from 207 to 150 ppm, we determined that the sulfur level of CG and winter RFG would increase from its 1998 level of 295 ppm to 300 ppm.

[13] Eastern U.S. refers to the eastern portion of the U.S. identified by API and NPRA in their sulfur control proposal. It consists of the eastern Texas, Oklahoma, Mississippi, Tennessee, Missouri, Illionois, Wisconsin, and all those states and the District of Columbia east of these states.

Sulfur levels in 2001-2003 were estimated from 2000 sulfur levels using the sulfur reductions which would occur from desulfurization units projected to be built and operating prior to 2004. These projections are described in Section IV.B.8. of the Final RIA. Based on the operation of these new units, we project that pool sulfur levels will decrease by 1, 21 and 37 ppm in 2001, 2002, and 2003. These reductions were applied uniformly to each fuel category with one exception. In 2003, a reduction of 37 ppm would have reduced RFG sulfur levels to less

Table 12 - Estimated Sulfur Levels Without Tier 2 Program														
	East CG		**East RFG**		**East SBREFA**		**East GPI**		**West CG**		**West SBREFA**		**West GPI**	
Year	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**
2000	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2001	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2002	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2003	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2004	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2005	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2006	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2007	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2008	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2009	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2010	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2011	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2012	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2013	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2014	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2015	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000

Table 13 - Estimated Sulfur Levels Under Tier 2 Program														
	East CG		**East RFG**		**East SBREFA**		**East GPI**		**West CG**		**West SBREFA**		**West GPI**	
Year	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**	**Average**	**Cap**
2000	300	1000	150	500	300	1000	300	1000	300	1000	300	1000	300	1000
2001	299	1000	149	500	299	1000	299	1000	299	1000	299	1000	299	1000
2002	279	1000	129	500	279	1000	279	1000	279	1000	279	1000	279	1000
2003	259	1000	120	500	263	1000	263	1000	263	1000	263	1000	263	1000
2004	120	300	120	300	191	450	150	300	120	300	208	450	125	300
2005	90	300	90	300	191	450	150	300	90	300	208	450	125	300
2006	30	80	30	80	191	450	150	300	30	80	208	450	125	300
2007	30	80	30	80	191	450	30	80	30	80	208	450	30	80
2008	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2009	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2010	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2011	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2012	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2013	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2014	30	80	30	80	30	80	30	80	30	80	30	80	30	80
2015	30	80	30	80	30	80	30	80	30	80	30	80	30	80

than 120 ppm, the corporate average standard in 2004. To avoid this, the RFG sulfur level was assumed to decrease to only 120 ppm in 2003 and the sulfur level of the remainder category of CG and RFG was decreased by 41 ppm instead of only 37 ppm. This results in a 37 ppm reduction in the non-California pool average sulfur level.

In 2004 and 2005, fuel subject to the corporate average standards, RFG and the remainder category of RFG and CG, was assumed to average at the corporate average standards, 120 and 90 ppm, respectively. The average sulfur levels of fuel certified to these standards may be below these levels due to refiners desire to maintain a safety margin between their actual sulfur levels and enforcement levels. However, the degree of this potential margin is not known and is not guaranteed by the applicable standards.

In 2004-2007, small refiners under the SBREFA program are governed by average standards which are a function of their current sulfur level. We estimated these standards for the 16 small refiners based on their sulfur certification data in 1998. In the east, the volume-weighted average of these standards was 191 ppm and in the west was 208 ppm. We assumed that these refiners would produce fuel at these sulfur levels until 2008, when the 30 ppm refinery average standard applies.

In 2004-2006, refineries covered by the geographic phase-in must meet a 150 ppm refinery average standard. We assumed that these refineries would produce fuel at this level.

For all categories of fuel, once the 30 ppm refinery average standard began to apply, we assumed that commercial gasoline in these categories would average at the standard, 30 ppm.

With respect to the maximum sulfur level possible in any fuel category, we based these levels on the maximum allowable sulfur level from any individual refinery in the category. The Complex Model places a limit of 500 ppm sulfur on RFG and 1000 ppm for CG; therefore these levels were applied to RFG and CG fuel categories, respectively, from 2000-2003.

Beginning in 2004, the maximum sulfur level of each fuel category was assumed to be the cap applicable to that category of fuel. Thus, these levels are simply a function of the final caps for these fuel categories.

2.3.3 Current Exposure FERs and Fuel Distribution

Our analysis of nationwide emissions required an estimate of the distribution of fuel in each fuel category across the 47-state region, on a summertime basis. We first developed distributions for three broader categories: East CG, East RFG and West. Population fractions presented in the NPRM Light-Duty Report were used to subdivide the 47-state area into these categories. The east/west split is estimated at 80/20. The east fraction was further subdivided into CG and RFG; all RFG is produced for the east, hence East RFG comprises 27 percent of 47-state fuel. This leave 53 percent of all 47-state fuel attributed to East CG.

An estimate of the fraction of fuel produced by SBREFA and geographic phase-in refiners in the east and west was then developed. The fractions of fuel represented by the eight small refiners in the east and the eight small refiners in the west and by the 14 refiners covered by the geographic phase in was estimated based on the 1998 gasoline production volumes of the refiners covered by these programs. These percentages are shown in Table 14.

Table 14 - Percentage of Fuel Produced by SBREFA and Exempted Refiners

	East	West
SBREFA	2%	9.5%
Geographic Phase-In	0%	20.5%

It was assumed that SBREFA and GPI refiners would only produce fuel for conventional gasoline areas. Thus, our estimate that two percent of all eastern fuel will be produced by SBREFA refineries means that 2.41 percent of all eastern CG (and zero percent of all eastern RFG) will be produced by these refineries. Applying the estimates from Table 15 resulted in the following fuel distribution by eastern CG, eastern RFG and western regions:

Table 15 - “Current Exposure” Fuel Distribution

Region	East				West		
	CG	RFG	SBREFA	GPI	CG	SBREFA	GPI
East CG	97.59%	0.00%	2.41%	0.00%	0.00%	0.00%	0.00%
East RFG	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
West	0.00%	0.00%	0.00%	0.00%	70.00%	9.50%	20.50%
47-State	51.72%	27.00%	1.28%	0.00%	14.00%	1.90%	4.10%

A 47-state distribution was derived by aggregating the three broad fuel categories by regional population fractions of 0.53 for eastern CG, 0.27 for eastern RFG and 0.2 for the west.

Our model estimates irreversibility by first calculating emissions at two sulfur levels: the “current” sulfur level which a vehicle is operating on, and the maximum fuel sulfur level the vehicles has ever been exposed to. The distribution presented in Table 15 reflects the “current” distribution of fuel categories; in other words, in the absence of sulfur irreversibility, this distribution would be used in conjunction with average sulfur levels in each category for a given year to estimate emissions in that year. Final emission rates were calculated for each fuel category using the average sulfur levels in Table 12 and 13; these FERs were then combined according to the 47-state distribution in Table 15 to generate nationwide “current exposure” final emission rates. It is assumed that vehicles will accrue the majority of their miles on the current exposure fuel, and hence the current exposure FERs were generated using the long-term sulfur sensitivity effects from Table 7.

2.3.4 Maximum Exposure FERs and Fuel Distribution

To estimate the effects of irreversibility, we calculated a second set of final emission rates only for SFTP-compliant vehicles, known as "maximum exposure" FERs. There FERs reflect emissions at the maximum sulfur level a vehicle has been exposed to. Because it is less likely vehicles will have accrued many miles at the maximum exposure sulfur level, these FERs were generated using the short-term sulfur sensitivity effects in Table 6. Maximum exposure FERs were developed for each fuel category, and weighted together using a maximum exposure fuel distribution. As mentioned above, there are four potential sources for high sulfur exposure: seasonal, categorical, temporal and variable. Each are discussed below.

2.3.4.1 Seasonal Exposure

Seasonal exposure applies in cases where the sulfur control applies only at certain times of year. Specifically, the Phase II RFG NOx performance standard only applies in the summer; hence, vehicles in these areas are exposed to Phase I RFG sulfur levels. Based on 1998 gasoline certification data, RFG sulfur levels averaged just over 200 ppm, while conventional gasoline averaged just over 300 ppm. All vehicles in RFG areas will thus be exposed to Phase I sulfur levels during the course of a year.

2.3.4.2 Categorical Exposure

Categorical exposure is defined as exposure to fuel produced across different fuel categories. This may apply to vehicles which travel and/or migrate geographically, i.e. between the east and the west, or it could result from exposure to fuel at from gas stations within a given area who receive their fuel from different sources.

Our only accounting for this type of exposure is for travel outside of RFG areas by vehicles residing in RFG areas. This travel is likely to occur regularly, because of the relatively small geographical area comprised by RFG areas. We therefore assume that all vehicles residing in RFG will be exposed to conventional gasoline and, in particular, to the maximum sulfur level for conventional gasoline at least once per year. Because conventional gasoline levels are higher than Phase I RFG levels, the "seasonal" exposure effect discussed above is superceded by this categorical exposure scenario.

Due to the complexity involved in trying to predict exposure across other fuel categories , we did not account for it in our analysis. Under the baseline case, this exposure would not affect inventory results because sulfur levels are estimated to be identical across categories (except RFG areas, which are already assumed to be exposed to conventional gasoline). Under the Tier 2 control program, the inclusion of SBREFA and the geographic phase-in increases the probability that vehicles operating on low sulfur fuel would be exposed to higher sulfur levels for a limited number of years. However, there is no reasonable way to estimate exposure at this level, given the uncertainties about where this fuel will be and how often or for how long vehicles might be exposed to fuel across categories.

To account for categorical exposure a second fuel category distribution is required - the distribution of fuel in terms of maximum exposure. The maximum fuel distribution which occurs when we assume that vehicles in RFG areas are exposed to conventional gasoline is shown in Table 16. This distribution applies to both the baseline and control cases.

Table 16 - "Maximum Exposure" Fuel Distribution

Region	East				West		
	CG	RFG	SBREFA	GPI	CG	SBREFA	GPI
East CG	97.59%	0.00%	2.41%	0.00%	0.00%	0.00%	0.00%
East RFG	97.59%	0.00%	2.41%	0.00%	0.00%	0.00%	0.00%
West	0.00%	0.00%	0.00%	0.00%	70.00%	9.50%	20.50%
47-State	78.08%	0.00%	1.92%	0.00%	14.00%	1.90%	4.10%

2.3.4.3 Temporal Exposure

Temporal exposure results from a lowering of the average sulfur level in a vehicle's "home" fuel category through the imposition of tighter sulfur control - primarily the Tier 2 control program. Under this scenario, vehicles which were on the road prior to the lowering of fuel sulfur levels will have been exposed to the higher pre-control sulfur levels. Temporal exposure was only relevant to the control case since the baseline case assumed constant sulfur levels for all years within each fuel category.

The effects of temporal exposure were modeled by assuming that for a given model year, the highest sulfur level it was exposed to was during its first year on the road (this assumes the fuel sulfur levels only decrease over time).   For a given model year, the maximum exposure FER was calculated for SFTP-compliant vehicles by applying the sulfur level from the calender year in Tables 12 and 13 which equaled that model year. For example, the maximum exposure FER for a 2003 model year SFTP-compliant vehicle was based on sulfur levels in calendar year 2003.

2.3.4.4 Variable Exposure

Although average sulfur level is commonly used to model the effects of sulfur on emissions, actual sulfur levels can vary considerably within a given fuel category. This is recognized in the Tier 2 program, which makes provisions for a standard "cap" as well as an average (for example, the 30 ppm average standard is linked with an 80 ppm cap). Under the pre-control case, the difference between average and cap is significantly higher; we estimate that the average sulfur level in conventional gasoline areas in 300 ppm, while the cap is estimated at 1000 ppm. Exposure to sulfur levels higher than the average within a given fuel category is a certainty in both the baseline and control cases; as such, the effects sulfur irreversibility under normal sulfur variability needs to be accounted for.

The proper accounting for variability in sulfur pools and its effect on current and maximum exposure FERs would require something close to a Monte Carlo simulation. To simplify the analysis, we assumed that sulfur levels would maintain average levels for most of a calendar year, but reach the cap for a long enough duration so that all vehicles would be exposed to the cap at least once per year.   It is reasonable to assume that under a random distribution of sulfur levels, at least one in 52 fill-ups (assuming one fill-up per week) will be on fuel which is at or near the cap.

To account for sulfur variability, therefore, the maximum exposure FER was calculated using the sulfur cap from the appropriate calendar year.   Combining this with the temporal exposure example discussed above, the maximum exposure FER for a 2003 model year SFTP-compliant vehicle would be based on the sulfur cap in calendar year 2003.

2.3.4.5 Nationwide Maximum Exposure FER

The nationwide maximum exposure FER for a given model was calculated by combining the maximum exposure FERs within each fuel category (generated to account for temporal and variable exposure as discussed above) according to he maximum exposure fuel distribution in Table 16.

2.3.5 National Average FER

The average FER (accounting for irreversibility) was calculated as a weighted average of the current exposure FER and the maximum exposure FER, according the sulfur irreversibility level. As detailed in Appendix B of the Tier 2 Regulatory Impact Analysis, this level for both HC and NOx is estimated to be 15 percent for LEV and Interim Tier 2 LDVs and LDTs, and 42.5 percent for final Tier 2 LDVs and LDTs. Thus, the national average FER was calculated as follows for model year MY:

$$(7)\ \text{National Average } FER_{MY} = \text{Current Exp } FER_{MY} * (1-IRR) + \text{Maximum Exp } FER_{MY} * IRR$$

Where:

IRR = 0.15 for LEV and Interim Tier 2, 0.425 for final Tier 2

In the generation of the emission inventories presented in the final rule, T2MODFRM.XLS was run with an irreversibility of 15 percent for the baseline case, and 42.5 percent for the control case. This serves to overestimate emission in the control case (underestimating benefits) since SFTP-compliant LEVs were assigned the Tier 2 irreversibility level.

An example of current exposure, maximum exposure and average FERs by model year are shown in Tables 17 and 18 , for calendar year 2015. The resulting FERs are contained in full in T2MODFRM.XLS (sheets LDGVNOX, LDGVHC, LDGT1NOX ,LDGT1HC, LDGT2NOX, LDGT2HC).

Table 17 - NOx Final Emission Rates: LDV Without Tier 2, Calendar Year 2015												
Model Year	Current Exposure				Maximum Exposure				Average (15% Irr)			
	N	N DR	High	Rep	N	N DR	High	Rep	N	N DR	High	Rep
1995	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363
1996	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363
1997	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363
1998	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363	0.457	0.059	2.689	1.363
1999	0.468	0.062	2.846	1.422	0.468	0.062	2.846	1.422	0.468	0.062	2.846	1.422
2000	0.473	0.064	2.925	1.451	0.476	0.064	2.930	1.460	0.474	0.064	2.925	1.452
2001	0.503	0.079	3.899	1.721	0.626	0.099	4.431	2.141	0.522	0.082	3.979	1.784
2002	0.454	0.073	3.753	1.571	0.574	0.092	4.298	1.985	0.472	0.076	3.835	1.633
2003	0.386	0.064	3.549	1.363	0.497	0.082	4.108	1.756	0.403	0.066	3.633	1.422
2004	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2005	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2006	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2007	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2008	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2009	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2010	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2011	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2012	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2013	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2014	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330
2015	0.357	0.060	3.462	1.273	0.463	0.078	4.026	1.655	0.373	0.062	3.547	1.330

Table 18 - NOx Final Emission Rates: LDV With Tier 2, Calendar Year 2015												
Model Year	**Current Exposure**				**Maximum Exposure**				**Average (42.5% Irr)**			
	N	**N DR**	**High**	**Rep**	**N**	**N DR**	**High**	**Rep**	**N**	**N DR**	**High**	**Rep**
1995	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267
1996	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267
1997	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267
1998	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267	0.424	0.055	2.574	1.267
1999	0.399	0.052	2.510	1.202	0.399	0.052	2.510	1.202	0.399	0.052	2.510	1.202
2000	0.387	0.051	2.478	1.169	0.386	0.051	2.471	1.168	0.387	0.051	2.478	1.169
2001	0.190	0.030	1.952	0.648	0.332	0.053	2.907	1.143	0.250	0.040	2.358	0.859
2002	0.171	0.027	1.880	0.592	0.372	0.061	3.260	1.302	0.257	0.041	2.466	0.894
2003	0.145	0.024	1.777	0.513	0.435	0.072	3.788	1.544	0.268	0.045	2.632	0.951
2004	0.098	0.017	1.605	0.353	0.223	0.038	2.788	0.799	0.151	0.026	2.108	0.542
2005	0.062	0.011	1.476	0.225	0.142	0.024	2.564	0.511	0.096	0.016	1.938	0.347
2006	0.043	0.007	1.405	0.156	0.064	0.011	1.824	0.233	0.052	0.009	1.583	0.189
2007	0.043	0.007	1.405	0.156	0.062	0.011	1.796	0.227	0.051	0.009	1.572	0.186
2008	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2009	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2010	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2011	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2012	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2013	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2014	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183
2015	0.043	0.007	1.405	0.156	0.060	0.010	1.761	0.220	0.050	0.009	1.557	0.183

2.4 Final Inventory Calculation

FERs from Equation (7) were combined according to the emitter fractions contained in T2MODFRM.XLS, “NOXHIGH” and “HCHIGH”; these fractions are the 47-state weighted versions of the fractions presented in M6.EXH.007 for the no I/M (OBD only) and I/M case. The final steps to calculating nationwide emission factors and then nationwide tonnage numbers are generally identical to that reported in the NPRM Light-Duty Report. The emission factors were derived from the following steps: 1) the weighted FERs for Tier 1 and later vehicles were used to estimate an emission rate for each model year in the fleet; 2) a travel fraction was multiplied by this emission level for each model year, and the results totaled to derived the fleetwide emission factor; and 3) the fleetwide emission factor for pre-Tier 1 cars and trucks from the lookup tables in worksheets “NOXEF” and “HCEF” were added to the result in step (2). The total fleetwide emission factor for each vehicle class was then weighted together by VMT mixes provided in the NPRM Light-Duty Report to generate a composite light-duty emission factor. Our revised estimates of light-duty VMT (derived from the air quality analysis, as described earlier in this memo) were applied to this emission factor to generate total 47-state light-duty tons an on annualized summer day basis. These results are presented in FRMINV.XLS, under the heading “T2MODFRM Raw Results”. We felt it appropriate to adjust these results using the locality adjustments in an attempt to account for the same locality-specific issues which drove the differences between the NPRM version of the Tier 2 Model and the air quality analysis results. We thus multiplied the raw emission inventory results by the appropriate locality adjustments; the results are presented in FRMINV.XLS under the heading “T2MODFRM Adjusted Results”, for VOC and NOx (the NPRM evaporative estimates were used to derive the total VOC results). These adjusted results are presented in Chapter 3 of the Regulatory Impact Analysis as the “Updated Tier 2 Model” results.